

Graphic CRT terminals—characteristics of commercially available equipment

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INTRODUCTION

"Who needs another review of Graphic CRT Terminals when so many good ones have recently been published?"

A reasonable question—

After all, Adams Associates is now offering the "Computer Display Review" — in which they're trying to do for the display field what they have been doing so effectively for the Computer field (with their "Computer Characteristics Quarterly"). The Air Force has just published their "Compendium of Visual Displays". Harry Poole's recent book, "Fundamentals of Display Systems" admirably meets the author's stated objective "... to provide fundamental data and illustrate basic techniques used in the design and development of display systems". Excellent books covering the use of displays in specialized application areas, like James Howard's new book "Electronic Information Displays for Management", are now available. Several survey articles* have recently appeared. Reasonably complete bibliographies of computer graphics literature have been published, such as the selected bibliography appearing in Ronald L. Wiginton's paper "Graphics and Speech Computer Input and Output for Communications with Humans" included in "Computer Graphics/Utility — Production — Art". These examples by no means exhaust the list—but they do emphasize the lead question "Why another one?"

The justification depends on two factors, I think. First, there appears to be a need for user oriented-hardware based information. (There is, to be sure, also a need for user oriented-software based information—but that will have to be the subject of someone else's paper.)

Second, there is also the need, I believe, to define terms. The user encounters words and phrases like "jitter" and "flicker-free" which are used to describe the performance and quality of a display system ... but the exact meaning of the terms are frequently left undefined. This lack of definitions is not the result

of a mass conspiracy by display manufacturers — but instead reflects the absence of standards and definitions in the field. Incidentally, one of the Society for Information Displays goals over the next few years is to establish a consensus on standards and definitions. This paper will attempt to clarify some commonly used display terms, as a guide to user understanding.

Generally, the discussion will be oriented to commercially available equipment.* Table I is a representative list of manufacturers of commercial graphic CRT terminals.

TABLE I

Manufacturers of Commercially Available CRT Graphic Terminals

Bolt, Beranek & Newman, Inc. (BBN)
Bunker-Ramo Corporation (BR)
Control Data Corporation (CDC)
Digital Equipment Corporation (DEC)
Ferranti, Limited
Information Displays, Inc. (IDI)
Information International, Inc. (III)
International Business Machines Corporation (IBM)
International Telephone & Telegraph Corporation (ITT)
Philco-Ford Corporation.
Sanders Associates
Scientific Data Systems, Inc. (SDS)
Stromberg-Carlson Corporation (SC)
Systems Engineering Laboratories, Inc. (SEL)
Tasker Instruments Corporation
UNIVAC

*This is a good place to start defining terms. By "commercially available" I mean relatively standard products regularly offered for sale — and meant to be used in an industrial rather than military environment. Admittedly, this is arbitrary (but, I hope, not capricious) and eliminates from consideration the numerous militarized command and control systems — and the fine display systems developed in University and Industrial Laboratories.

Photographs of representative terminals are included in Figure 1.

Section 2 of this paper briefly reviews the constituent elements of a typical Graphic CRT terminal.

Prices of these terminals range from approximately \$20,000 to \$280,000. Generally, as discussed in an earlier article,⁸ price and performance are related. However, because there are many factors that affect performance, and the importance of each factor depends upon the application, the cost-performance relationship is not a simple one. Section 3 of this paper is a discussion of various factors which affect performance.

Block diagram

A typical block diagram for a Graphic CRT Terminal is shown in Figure 2. Generally, the terminal consists of:

A *Direct View Cathode Ray Tube* with associated analog deflection and video (intensification) circuitry, plus . . .

A *Display Generator* which contains several types of function generators to produce graphic elements, plus (occasionally) . . .

A *Storage Element*, plus

An *Interface* between the computer and terminal, plus . . .

A variety of *Input Devices* from the display to the computer.

Cathode ray tube

The CRT may be deflected electrostatically, or electromagnetically or by a combination of both. Commonly used configurations are illustrated in Figure 3. Table II lists the deflection system used by various manufacturers.

Most commercially available Graphic CRT Consoles use random positioning to produce a picture. That is, the beam is moved to the desired location on the screen and then controlled to produce the graphic element (line, character, etc.). This is in contrast to the raster scan used in a TV set (and in most alphanumeric CRT inquiry units). Philco is one of the few suppliers of a raster scan graphic CRT terminal. Figure 4 illustrates the difference between random positioning and raster scan.

Tubes are available with a variety of conventional phosphors offering a choice of color as well as persistence. Bolt Beranek and Newman Teleputer System uses a CRT with storage screen.

So that an optically projected image can be combined with the electronically generated image, CRT's in terminals supplied by Bunker-Ramo and Stromberg-Carlson have a window through which a picture

TABLE II

Deflection Systems Used by Various Manufacturers

Manu- facturer	Dual Deflection		
	Electro- static	Electro- static + Magnetic	Magnetic + Magnetic
BBN	x		
BR			x
CDC	x		
DEC		x	
Ferranti		x	
SC			x
IBM			x
IDI		x	
III			x
ITT		x	
Philco			x
Sanders			x
SDS		x	
SEL			x
Tasker			x
UNIVAC			x

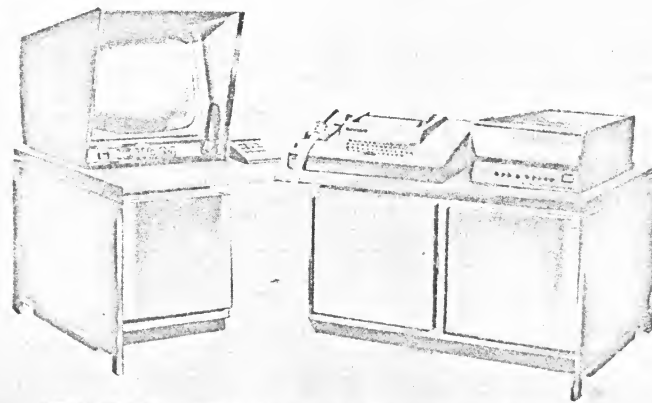
can be projected onto the screen. This is illustrated in Figure 5.

Display generator

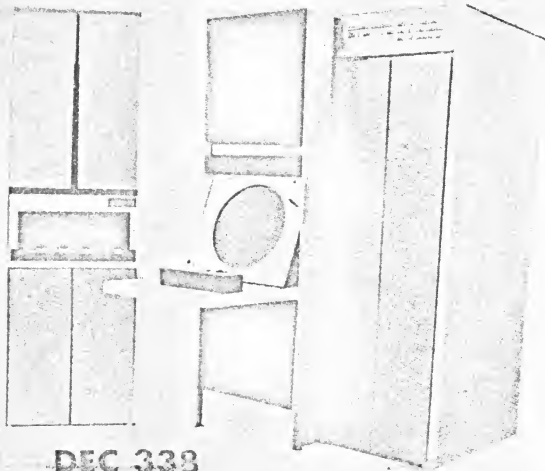
The Display Generator contains the circuitry which interprets the computer digital data word and translates it into analog signals to generate the graphic elements on the CRT. The Display Generator is essentially just a digital-to-analog converter (D/A). Typically, the Display Generator will include such function generators as a character generator, a vector (line) generator, a circle generator, position generators (conventional D/A converters) and a dot generator.

All of the graphic elements produced by the various function generators could also be produced by appropriate computer software. For example, letters could be programmed as a series of dots, or short line segments. However, each dot or line segment requires a separate digital instruction from the computer and this tends to increase the computer programming. Therefore, although there are under development several interesting and commercially promising graphic terminals using this technique, all currently available commercial terminals, except the BBN Teleputer units, use special purpose function generators.

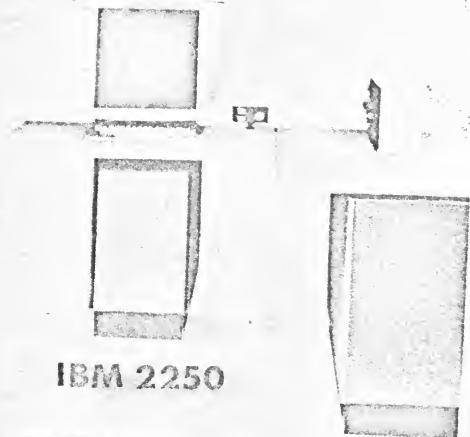
Instead of using a separate character function generator in the Display Generator, the Stromberg-Carlson console uses a special CRT which shapes the cross-section of the electron beam into the desired character. This is accomplished by inserting a stencil mask in the



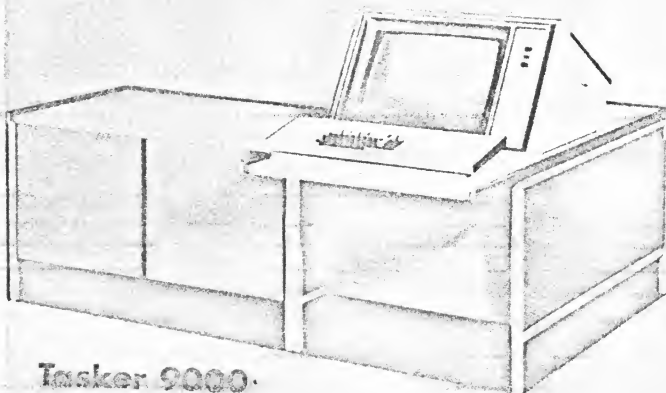
IDIOM...IDI Input-Output Machine



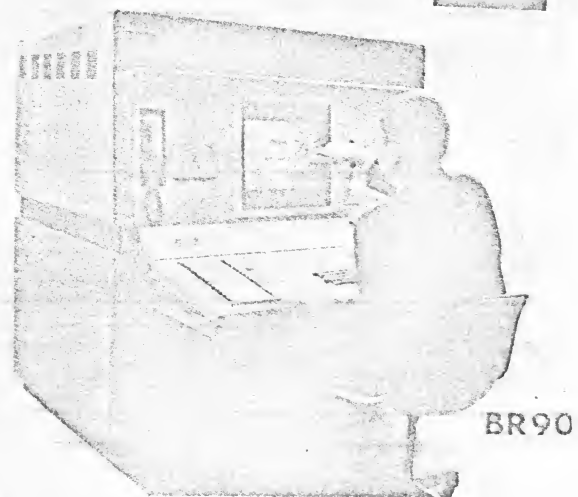
DEC 338



IBM 2250



Tasker 9000



BR90

Figure 1—Typical graphic CRT consoles

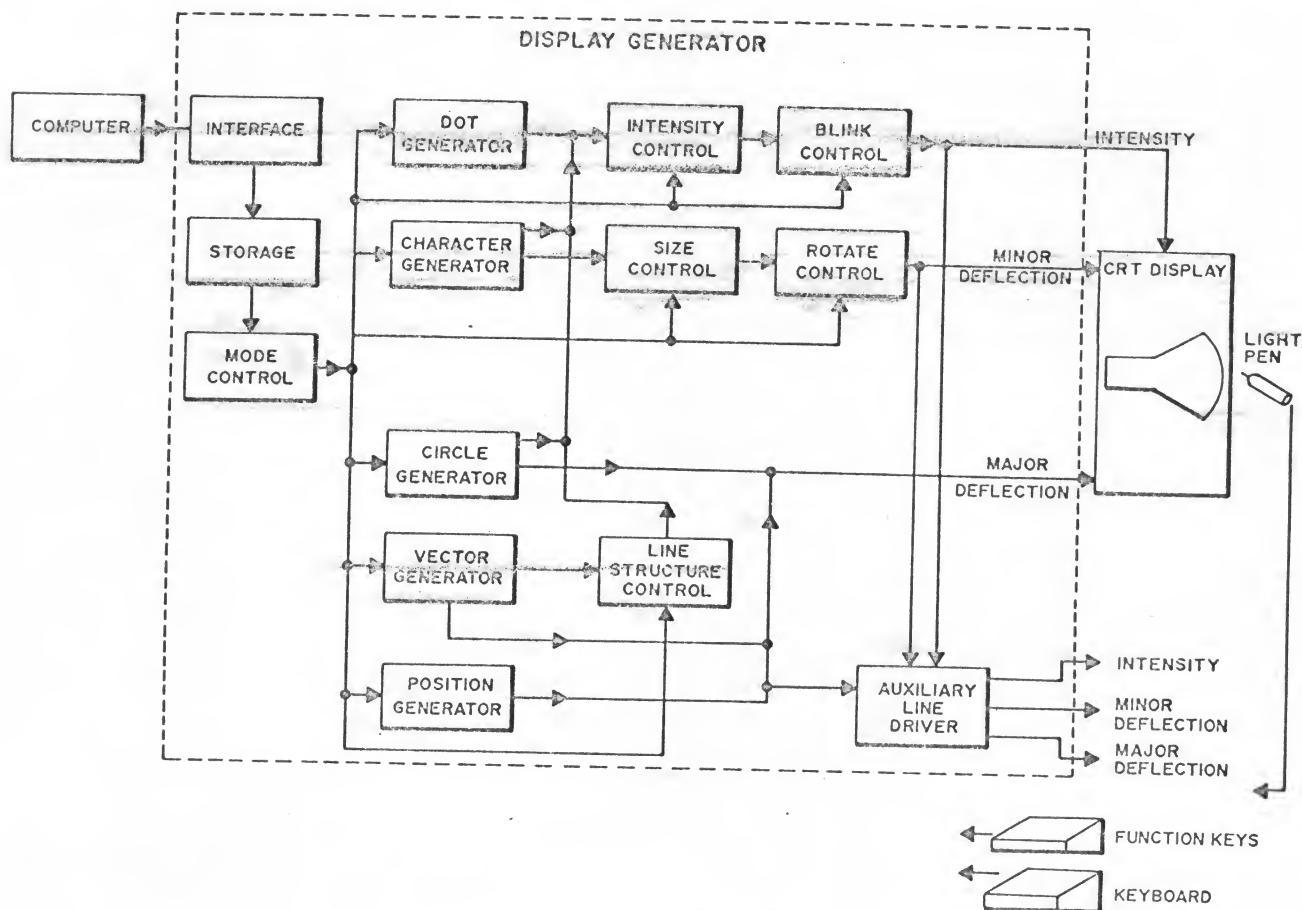


Figure 2—Graphic CRT display

CRT. The beam is extruded through the appropriate aperture and the beam cross-section assumes the shape of the selected character.

Terminals often contain several other modules which modify the outputs of the function generators. In IDI terminals, for example, a digital size control is usually associated with the character generator. By using one or two digital bits, two or four character sizes can be programmed. A line structure control is sometimes included. This permits programming a line to be dotted, dashed, or dash-dotted as well as solid. While this could also be done with software, the hardware alternate allows the control to be done with one or two digital bits, without increasing line drawing time. Hardware is often included so that the intensities of graphic symbols can be digitally controlled. Any of the graphic elements can also be made to blink, that is, turned off and on at low frequency (about 5 cps).

At the input to the Display Generator is a Mode Control. The Mode Control decodes the computer data word and activates the appropriate function generators

and modifiers. In most terminals, several other hardware functions are assigned to the Mode Control. For example, characters can be arrayed in typewriter fashion, as on this page, with the Mode Control, Spacing can be automatically adjusted to character size. When the end of the line is reached, the line can be automatically reset to the left hand margin (or to a programmed margin) and then advanced to start the next line of characters. Characters can be rotated CCW by 90° and written vertically starting at the bottom of the screen; or the characters can be superscripted and subscripted. Logic for connecting (or stringing) line segments can be included. Once the first line is established, only the successive end points of the line segments need be outputted to the Display Generator. Special modes for curve or graphic drawings can be incorporated. The Mode Control may include address and index registers to facilitate programming.

The design of the Mode Control represents the manufacturer's trade-off decision between computer software and display hardware.

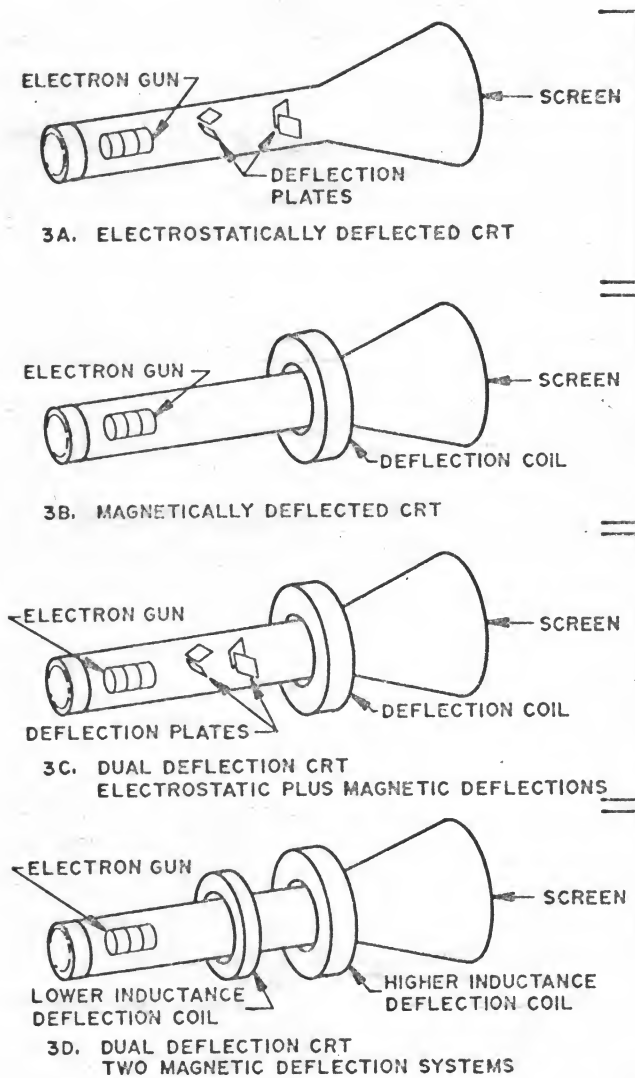


Figure 3—Commonly used deflection systems

Storage

In most CRT graphic terminals, the image must be repeated (refreshed) in order to appear flicker-free* to the user. If a terminal does not contain a storage device, the computer must continually refresh the display.

Many modern computers have a memory configuration which can be used to refresh the display without interrupting other computations. Where this is not possible, a buffer memory is available within a display. Commercial terminals use core memories, delay

*"Flicker-free" is a term which will be discussed in Section 3.

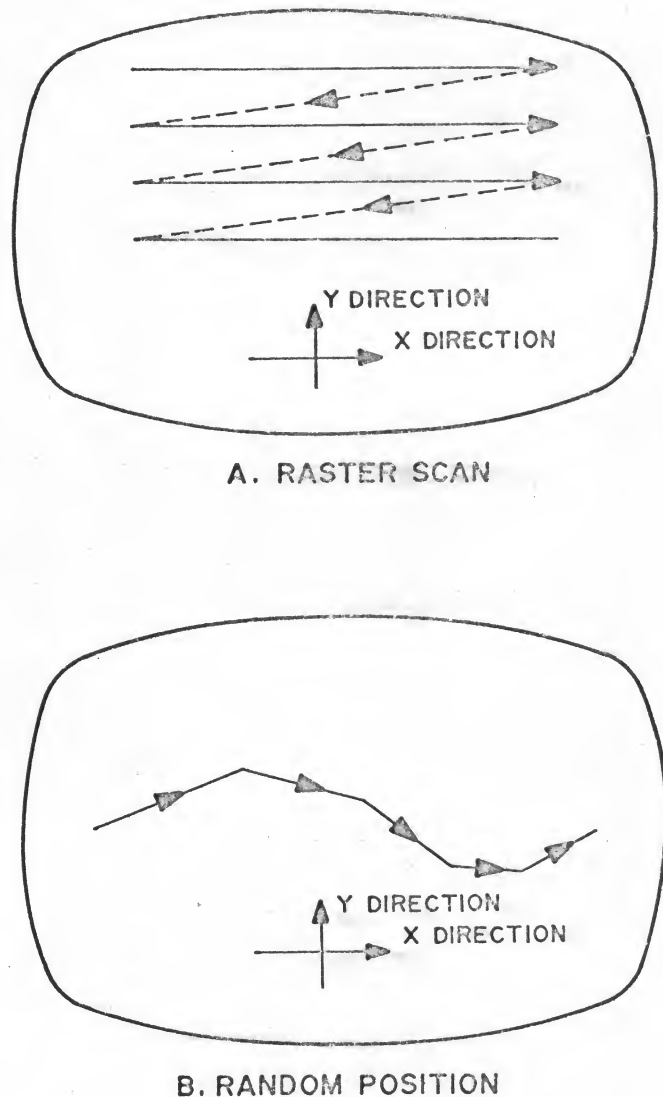


Figure 4—Basic deflection schemes

lines, and drums. With the availability of low cost, high-speed, general purpose, digital computers, it becomes feasible to consider including a digital computer in the CRT graphic terminal. BR, DEC, and IDI offer terminals in which the digital computer is an integral part of the display and provides functions of storage, plus some of the hardware mode control features.

As stated earlier, BBN terminals use a storage CRT so that the image need be written only once and the local memory is not required. However, these storage tubes cannot be easily used in systems in which the operator wants to use a light pen to input graphical data to the computer.

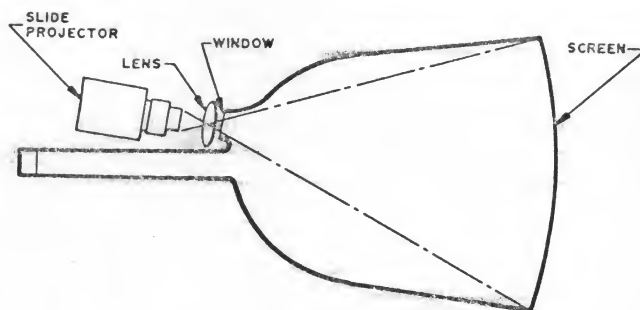


Figure 5—Using a ported (window) CRT to combine projected

Interface

Because CRT graphic terminals are available from manufacturers who do not make the computer with which the display is to operate, an interface is usually required to convert the computer output into a form suitable for the terminal. The conversion may include reorganization of the data words, conversion of logic levels, and generation of appropriate communication signals.

Input devices

The discussion thus far has been about a one-way device; information is received from a computer, converted in the Display Generator, and presented as a graphic image on a CRT. However, one of the basic reasons for the increasing acceptance of CRT graphic terminals is the availability of an operator channel from the display back to the computer. The operator can converse with the computer on-line* and in real-time* using input devices such as a light pen, joy stick, track ball, Rand tablet, and function keys.

Factors which affect performance

As can be inferred from the foregoing discussion, a graphic CRT terminal is a conglomerate of devices, each of which has a range of characteristics which can affect the performance and useability of the terminal. For convenience, the various factors which contribute to the effectiveness of the terminal can be grouped into three categories:

1. Those which affect the *data content* . . . that is, how much information can be displayed simultaneously without flickering objectionally and with the graphic symbols large enough to be

*"On-line" and "real-time" are fairly abused terms in the computer world, and are used here without being rigorously defined. The sense is to describe J.G.R. Licklider's ". . . 'on-line people,' which is to say, people who are interacting directly with information and with information processors."

easily read; or, when small, to be easily distinguishable.

2. Those which affect the *quality* of the display . . . that is, how the display looks aesthetically to the observer, and
3. Those which affect the *ease of use* . . . both from a human factors standpoint and from a systems programming standpoint.

There is, of course, some "spill-over" among categories, but the categories provide a convenient frame of reference for the discussion which follows.

Data content

The amount of data which can be displayed simultaneously, without appearing to flicker cannot be determined until one explores the concept of "without appearing to flicker."

"Without appearing to flicker" or alternately, "flicker-free" is not a factor to which a single number can be assigned (as most manufacturer's are prone to do). Perceptible flicker varies with individuals and has been found to be a function of such factors as the individual's age, the color of the light, whether the individual is looking directly at the object or looking out of the corner of his eye, the brightness, the brightness variation, the variation between light and dark, and the size of the flickering object. Typical studies of flicker¹⁰ use phrases like "the average observer" or "90% of the observers" to bound statements about observable flicker. H. Poole² presents a curve, reproduced as Figure 6, which relates critical frequency (frequency below which flicker is observed) to brightness. However, the data in Figure 6 make no allowance for the persistence of the CRT phosphor.

The typical CRT non-storage phosphor used in commercially available consoles retains an image for times* ranging from about 40 USEC to 0.6 seconds, as summarized in Table III. For these typical phosphors, J. Bryden¹⁰ has experimentally determined (for a specified test condition) the "lowest refresh rate which will give freedom from flicker for 90% of the observers," and this experimental value is tabulated in Column 6 of Table III. Note that although Figure 6 indicates a critical frequency of about 50 cps at a

*Phosphors are categorized by the length of time required for the image to decay to 10% of its initial value. Phosphor classifications are summarized below.

Time Required to Decay to

10% of Initial Brightness

Less than 1 USEC
1 USEC to 10 USEC
10 USEC to 1 MS
1 MS. to 0.1 SEC
0.1 SEC to 1 SEC
Longer than 1 SEC

Phosphor Classification

Very Short (VS)
Short (S)
Medium Short (MS)
Medium (M)
Long (L)
Very Long (VL)

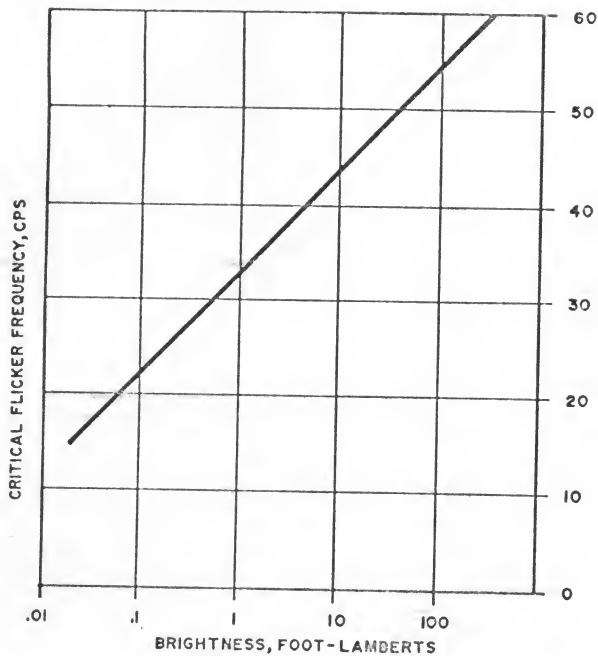


Figure 6—Critical flicker frequency as a function of brightness

brightness of 50 foot-lamberts, the data in Table III show that 90% of the observers will not see flicker at frequencies greater than 21 cps to 38 cps, depending on phosphor. J. Bryden presents another table (Table 4.1) which lists "Refresh Rate (cps) for Flicker Threshold of Average Person at 50 foot-lamberts". These values, listed in Column (7) of Table III range from 17.5 cps to 33.5 cps depending on phosphor.

The purpose of detailing the varied results is to emphasize that a simple statement of "flicker-free" presentation is an inadequate user (or manufacturer) specification. (Of course, if the console uses a storage CRT, the image need not be refreshed until intentionally erased, or until decay after relatively long time measured in minutes; and the question of a flicker-free presentation is not meaningful.)

a) Frame Rate

The basic problem, then, is deciding how many times per second the image needs be repeated (or refreshed) so that it does not appear to flicker to the observer. Having decided this flicker-free rate, the time available to write a complete frame of data is simply the reciprocal of the rate . . . the faster the refresh rate, the shorter the time available per frame.

Why not always use a longer persistent phosphor, thereby reducing frame rate and increasing time per frame? For several reasons: (1) Shorter persistent

phosphors, such as the P31 (medium-short) tend to be more visually efficient and look brighter to the user. This is illustrated by Column (5) of Table III which lists J. Bryden's test results showing the brightness for several phosphors under identical test conditions. (2) Long persistent phosphors, like the P19 and P28, are more easily burned than the medium-short persistence P4 and P31. (3) If the terminal is displaying a rapidly moving graphic element, the long-persistent phosphors tend to smear the image. (4) Brightness is a direct function of frame rate.

In order to provide a standard reference in the balance of this paper, *all frame-time dependent values and references to flicker-free presentations in the following discussions are based on a 40 cycle frame rate (or 25 MS frame interval)*. Keep in mind, however, that the data content can be increased in direct proportion to frame interval. For example, if a flicker-free data content of 250 points is quoted, it is understood that the calculations are based on 25MS frame interval.

If, for example, in a particular system, with a particular phosphor, a frame interval of 50 MS (frame rate = 20/second) were acceptable, the number of points could be increased to 500.

b) Deflection Amplifier Response

A primary parameter of a CRT display is the speed with which the beam can be positioned. In random positioned systems, the beam can be moved anywhere on the screen in times ranging from 3 USEC to 100 USEC. A complete specification of deflection time should include a statement of the accuracy to which the beam has settled within the quoted time. For example, the quoted random positioning time of IDI systems is based on settling to within $\pm 0.1\%$ of final value. Until recently, electrostatically deflected CRT's tended to exhibit the fastest random positioning times. The new electromagnetically deflected Tasker console, however, is reported to have random positioning times as fast as commercially available electrostatic units.

The number of random dots which can be displayed, flicker-free, ranges from 250 to 8300.

If the data can be properly formatted, it may be possible to organize the information so that full screen random positioning from dot to dot is not required. Under these circumstances, the small angle (incremental) positioning time of the deflection amplifier is critical. In commercially available equipment, this ranges from 1 USEC to 10 USEC. Therefore, the number of incremental dots which can be displayed flicker-free ranges from 2500 to 25000.

Note that these factors are based on the assumption that the system uses random positioning. There are systems, however, which use a raster scan similar to that used in a conventional television set. Such systems require complete formatting of the data. However, by doing so, as many as 1,000,000 dots can be displayed flicker-free, compared to a maximum of 25,000 dots in a random positioning system.

As illustrated in Figure 3C and 3D, and Table II, many consoles employ dual deflection. This second deflection channel, typically wide bandwidth (DC to 50 MC) and small angle deflection, is used for character writing.

c) *Character Writing Time*

Character generators available in commercially available terminals write a character in times ranging from 2 USEC to 100 USEC. To these times must be added the positioning time (ranging from 3 USEC to 100 USEC random or 1 USEC to 10 USEC, small angle). Therefore the number of random characters that can be displayed flicker-free ranges from 125 to 5000, and the number of formatted character (text) that can be displayed flicker-free ranges from 220 to 8300. As a comparison, a typical double spaced typewritten page contains about 2500 characters.

d) *Line Drawing Time*

Two types of vector (line) generators are offered in commercially available equipments. One type requires a fixed time to draw a line regardless of line length, while the other requires a time proportional to line length. Typical fixed time vector generators require from 30 to 150 USEC to draw lines up to full screen size, while the proportional vector generators have line drawing speeds ranging from 0.5 USEC per inch to 150 USEC per inch. This means that the fixed time vector generators can draw between 160 and 830 flicker-free line segments per frame. Depending on CRT screen size, this can represent up to 16,000 inches of line. Proportional vector generators can draw from 160 to 50,000 inches of flicker-free line per frame.

e) *Circle Drawing Time*

Hardware circle generators available with some terminals can generally draw any size circle in from 100 USEC to 300 USEC. This means that from 83 circles to 250 circles can be displayed flicker-free.

f) *Logic Time*

In addition to the actual time required to deflect a beam and write the various functions, the logic in the Display Generator, the logic of the com-

puter, and the memory cycle time will affect the amount of data which can be displayed. For example, the word organization of the terminal may require that the generation of each graphic element be controlled by several data words. Elapsed time from the display's request for a data word and the terminal's set-up is in the order of 1 to 4 USEC. If 1,000 data words were required per frame (a typical value) and between 1 and 4 USEC were consumed in data transfer and logic set-up, 4% to 16% of the frame time would be consumed and the data content would be reduced by that amount.

g) *Resolution*

Resolution determines such things as the smallest readable character that can be displayed, and the minimum spacing that can be discerned between lines. Basically, CRT beam spot size determines resolution. In commercially available terminals, the nominal spot will range from .01" diameter to .03" diameter.* However, spot size might vary by a factor of 3:1 (on the same terminal) because of beam intensity and spot position on the screen (better in the center, poorer at the edges). Some terminals use dynamic focussing techniques to keep the spot size relatively constant over the display area.

Without being rigorous about defining resolution and spot size, one can observe that the resolution of commercially available terminals is such that the number of readable characters per inch ranges from about 3 to 11. For comparison, a Pica Typewriter spaces characters 10 per inch, and an Elite Typewriter spaces characters 12 per inch.

Addressability is sometimes confused with resolution. Addressability is a statement of how many digital positions can be programmed (but not necessarily distinguished) along each axis. Typical terminals offer 9 bit (512) or 10 bit (1024) addressable locations.

h) *Screen Size*

Screen size affects data content primarily from the standpoint of resolution. CRT's used in commercial terminals generally range from 16" round to 24" round,* with available display areas of from 10" $\times$ 10" to 16" $\times$ 16". Therefore, the number of readable characters per line can range from 30 (based upon a 10" line of 3 characters/inch) to 176 (based upon a 16" line of 11 characters/inch).

*Determination of spot size, and the correlation between spot size and resolution is another area requiring the attention of a standards committee. J. Bryden's paper includes an informative discussion of his measurement techniques.

*Except the BBN terminal which uses a 5" CRT.

i) Overlays

Static information can be superimposed on the beam written data by projecting pictures (slides) through an optical port in the CRT. Typical systems can select from among 25-150 slides.

Quality

Several factors affect the image quality. Some of these factors may also affect data content, as indicated in the following discussion:

a) *Accuracy*—Accuracy describes how the programmed position of the beam corresponds to some eternal reference. For example, if a grid were scribed in the face of the CRT and the beam were programmed with a digital instruction which should cause the beam to fall at a grid line intersection, the variance between the beam position and the intersection is the accuracy. Commercially available systems have accuracies ranging from 1% to 5% of full scale. (Compared, for example, to a reasonably well adjusted frame TV set which ranges from 10% to 15%.) Generally, pictures drawn with this accuracy are quite acceptable to the observer *provided* there is no attempt to superimpose the electronic image with a mechanical reference. The presence of the mechanical reference will emphasize the inaccuracy of the display.

b) *Short-time Stability*—Short-time stability of the image will affect the observer's reaction to it. Small movement of the graphic element, called jitter, can be quite objectionable when it occurs at low frequencies (less than 10 cps). Jitter results mainly from a beat between the frame rate and the power line frequency (or submultiple frequency). In an adequately shielded terminal, the jitter is about 0.5 to 1 spot—but even this value can be disturbing to the user.

Two methods are used to reduce or eliminate the apparent jitter. One is to maintain the frame rate at such a value that the beat frequency is relatively high . . . typically 20 cps. Although jitter still may be present, the graphic element is moving so fast that, to the observer, the line or dot simply thickens a bit. Hence, the resolution is affected, but the image appears stationary. This technique is especially successful when used with longer persistent phosphors.

Alternately, since the jitter most frequently comes from stray magnetic fields, the display frame rate can be locked to the line frequency and the jitter essentially eliminated.

c) *Repeatability*—When the beam is programmed to the same location from various places on the

screen, the successive dots will probably not be superimposed. The spread, called repeatability, may range from 1 spot size to 10 spot sizes. In commercially available equipment this effect may be particularly disturbing when various line segments are programmed to start from the same point, but, because of repeatability, they do not.

d) *Brightness and Contrast*—If the display is to be used in a normally lighted room, it is important that the presentation be bright or have a high contrast ratio. Typical terminals produce 20 foot-lambert to 50-foot lambert presentations. Medium-short persistent phosphors, such as the P4 and P31 do produce bright, easily read displays, but these phosphors require relatively high frame rates to reduce flicker. Long persistent phosphors, such as P19 and the P28, reduce the frame rate requirements at the expense of brightness. Therefore, displays using long persistent phosphors may require subdued room illumination. Contrast can be enhanced with neutral density filters. Although these filters reduce total brightness, they do increase and enhance the readability of the display.

e) *Phosphor Color*—Phosphors are available which produce white, green, yellow, blue, and red outputs (and shades in-between). The medium-short persistent phosphors are generally in the white, green and blue range; while the long persistent phosphors are in the orange, yellow range. See Table III.*

f) *Graphic Symbol Construction*—Graphic elements can be constructed in a variety of ways¹¹ . . . some of which enhance the quality of the display and others which tend to detract from it. For example, characters formed from a 5×7 dot format may be readable but not aesthetically satisfying. Other graphic elements constructed from a series of dots may be readable, but not pleasing.

Stroke characters usually produce acceptable quality. The beam forming and monoscope* techniques permit a wide range of character formats, with few limits on character style. Higher resolution dot formats, typically 16×16, are also capable of producing excellent quality symbols.

Ease of use

There are two categories discussed in this section; those which are based on human factor considerations and those which are based on programming considerations.

a) *Human Factors*—The plane of the CRT screen

*The monoscope produces character video by electron beam scanning of a target on which characters have been drawn in ink. Typical commercial monoscopes, such as the Raytheon Symbolray, use targets with 64 or 96 symbols.

*Table III is shown on page 159

ranges from vertical to approximately 45° from the vertical. Generally, this is fixed although a CDC unit features tiltable display screen (essentially continuously variable between vertical and horizontal).

A variety of light pen configurations are available ranging from a simple penholder type to a gun type. Some pens are relatively heavy while others are light weight. Some use a very flexible cable and others use a rather stiff cable or coil cord. Aiming circles are provided with some light pens so that the operator knows where the sensitive area of the light pen is pointed. Activating switches for the light pen include mechanical shutters on the pen, electrical switches on the pen, knee switches and foot pedal switches.

Other operator input devices are available on various consoles. Alphanumeric keyboards and function keys are used. Some function keys use plastic overlays for additional coding. Track balls and joy sticks are preferred by some users. The Rand Tablet, which provides an easy method for graphic input, is available as an accessory in several systems.

Operator controls on commercially available terminals range from only an on-off power switch, to a group of manual adjustments for various display parameters.

Servicing facilities incorporated in terminals range from logic card extender to elaborate maintenance panels, which include register lights and test pattern generators.

Terminal packaging ranges from multiple cabinet configurations, with the display console separated from the display generator, to single cabinet integrated units which occupy 10-15 square feet of floor space, and are 4-5 feet high.

b) *Systems Programming*—The display command structure influences system programming. Two common types of command structures are shown in Figure 7. In one approach, illustrated by Figure 7A, each data word is completely self-contained and has a mode instruction and all other information required to define a graphic element. In contrast, the word organization currently favored (Figure 7B) establishes a mode of operation with one word and then uses a series of succeeding data words to program identical kinds of graphic elements. Figure 7B also illustrates a word organization which includes computer-type instructions such as JUMP and JUMP AND SAVE.

Some graphic terminals such as the CDC, DEC, IBM, and IDI are designed so that more than one display console can be driven from a common Display Generator. These other consoles may be slaved (and have identical information) or they may have

FUNCTION	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
POSITION	Mode		X Position												Y Position										
	00																								
DOT	Mode		X Position												Y Position										
	01																								
CHAR.	Mode					CHAR.1							CHAR.2					CHAR.3							
	10																								
VECTOR	Mode		X Position												Y Position										
	11																								

FIGURE 7A

TYPICAL WORD ORGANIZATION

(MODE CONTROL CODE IN EACH WORD)

FIGURE 7B

TYPICAL WORD ORGANIZATION

(CONTROL WORDS AND DATA WORDS)

0	1	2	3	4	5	6	7	8	9	10	11	
1	0	1	I	P								
ADDRESS												Program Control Word
1	1	1	1	0	LP	F	TYPE	INT	BL*			Vector Mode Control Word
0					X Coord				Z			Vector Data Word Pair
					Y Coord				BL			
1	1	1	0	0	LP				INT	BL*		Dot Increment Mode Control Word
0					ΔX			ΔY	Repeat	Z		Dot Increment Data Word
1	1	1	0	1	LP				MAR	INT*	BL*	Symbol Mode Control Word
0					CHAR				ΔS	INT	BL	Symbol Data Word
1	1	1	1	1	LP				ΔS	INT	BL	Packed Symbol Mode Control Word
					CHAR 1				CHAR 2			Packed Symbol Data Word (77 ₈ = escape)
LP = disable light pen BL = enable blink Z = blank F = frame sync INT = 00 - normal 01 - dim 10 - bright 11 - off TYPE = 00 - Position 01 - Position, Write Dot 10 - dash 11 - solid												X, Y = 001 +1 010 +2 111 -1 110 -2 Others - no increment ΔS = 00 - normal, no offset 01 - small, superscript 10 - small, subscript 11 - small, no offset MAR = 00 - Npp 01 - set margin 10 - return to margin 11 - return to margin and line feed

*These bits do not actually control the Display, but are included to provide programming mode compatibility.

Figure 7—Typical word organization

different information. Such displays may be photographed or used to produce wall size pictures or immediate hard copy.

SUMMARY

This paper has discussed the characteristics of commercially available terminals from an equipment viewpoint — not from an applications viewpoint. One can list a number of current and potential applications for CRT graphic terminals, but data which describe terminal requirements in terms of these applications are

scarce. For example, the line drawing needs of a terminal used by civil engineers for cut-and-fill analysis may be quite different from those of an engineer using the terminal to design integrated circuit masks. Adams Associates, in their "Computer Display Review" formulated several typical presentations including a schematic diagram, floor plan, and weather map — and, using terminal manufacturer's supplied performance specifications, analyzed how long each terminal would take to write the display.

Generally, though, the terminal user considers his data (applications) content requirements proprietary, and seldom publishes his findings. We can expect, however, that over the next few years, many more "How Application Factors Determine CRT Terminal Specifications" papers to appear.

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TYPE (1)	EMISSION COLOR		PERSISTENCE (4) (SEC)	LUMINOUS OUTPUT FOOT-LAMBERTS (5)	FLICKER FREE RATES (CPS) AT 50 FT. - LAMBERTS	
	FLUORESCENCE (2)	PHOSPHORESCENCE (3)			Average Person (6)	90% of Observers (7)
P4	White	White	6×10^{-5}	5.2	33.5	38.
P7	Blue	Yellowish Green	Blue 5×10^{-5} Yellow 5×10^{-1}	5.2 3.0	29.8	33.
P19	Orange	Orange	2×10^{-1}	3.0	17.5	21.
P28	Yellow Green	Yellow Green	6×10^{-1}	5.2	31.4	38.
P31	Green	Green	4×10^{-6}	12.0	32.5	36.

NOTE: Column (2) Fluorescence is the light emitted by the phosphor during the period of electron beam excitation.
Column (3) Phosphorescence is the light emitted by the phosphor after the electron beam excitation is removed.
Column (4) Time for initial output to decay to 10% of initial value.
Column (5) From Table 3.1 of Reference 10.
Column (6) From Table 4.1 of Reference 10.
Column (7) From Figure 4.4 of Reference 10.

TABLE III
TYPICAL PHOSPHORS USED IN COMMERCIALY
AVAILABLE GRAPHIC CRT TERMINALS.....
A SUMMARY OF CHARACTERISTICS.